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23 September 1991

Monique Dillon
Resident Representative
Office of Naval Research
Charles S. Draper Laboratory, Inc.
555 Technology square, MS54
Cambridge, MA 02139-3539

Dear Ms. Dillon,

Please find enclosed the Final Technical Report and Report of Inventions (Form 882) for our ONR contract N00014-87-K-0536, "Upper Ocean Mixing: The Use of Algal Pigments as Biological Tracers for Turbulent Diffusion", Principal Investigator: Nicholas A. Welschmeyer. Thank you, in advance, for your patience in awaiting the arrival of this report.

Some notes are probably warranted to recount the history of this contract, to clear any confusion. The contract originated as an ONR Young Investigator Program award while I was at Harvard University (N00014-87-K-0536). In 1990 I took a new position at San Jose State University (Moss Landing Marine Laboratories). The existing contract was transferred to San Jose State University Foundation and issued a new contract number, N00014-89-J-1615. However, there was no change in scope for the project. The Final Technical Report, enclosed herein, covers work accomplished throughout the whole project, referenced by the two contract numbers above; I hope this is satisfactory.

If there are any questions, please do not hesitate to call. Thank you again for your attention to these matters.

Sincerely,

Nicholas Welschmeyer
Professor, Oceanography



cc:
Paul Biddle, ONR Resident Representative, Stanford Univ.
Diane Kruse, San Jose State University Foundation
Merrily Sterns, Office for Sponsored Research, Harvard Univ.
Bernard Zahuranec, ONR, Code 1122B, Arlington VA
✓Defense Technical Information Center
Director, Naval Research Laboratory

# Upper Ocean Mixing: The Use of Algal Pigments as Biological Tracers for Turbulent Diffusion



N00014-87-K-0536



Final Technical Report

Office of Naval Research

Principal Investigator: Nicholas A. Welschmeyer

Moss Landing Marine Laboratories
P.O. Box 450
Moss Landing, CA 95039

## ABSTRACT

The goal of the proposed research was to develop an in situ method for determining upper-ocean mixing rates using algal pigments as natural biological tracers. The work focused specifically on *xanthophyll-cycling*, a well known series of reversible, light-sensitive pigment transformations that occur in all higher land plants and many marine phytoplankton species. Laboratory work was initiated to define the rate constants for xanthophyll-cycling in microalgal cultures, and to develop a quantitative understanding of the influence of light intensity on the xanthophyll-cycling process. Field work was completed which verified that xanthophyll-cycling processes measured in natural phytoplankton populations indeed reproduced our laboratory observations.

A Monte-Carlo computer model was developed in order to study the influence of xanthophyll-cycling on algal pigmentation under known conditions of simulated mixing. The collective results from physiological experimentation and simulation modeling were used to develop a field method for calculating ocean mixing rates (Welschmeyer and Hoepffner, 1991; Welschmeyer 1991). The work has now identified previously unrecognized relationships between xanthophyll-cycling and cellular fluorescence, which are of potential importance in exploiting single-cell characteristics as novel tracers of ocean mixing. This new work is continuing in our laboratory.

## PUBLICATIONS AND MANUSCRIPTS RESULTING FROM CONTRACT N00014-87-K-0536

### PUBLICATIONS:


Chisholm, S.W., R.J. Olson, E.R. Zettler, R. Goericke, J.B. Waterbury, and **N.A. Welschmeyer**. 1988. A novel, free-living Prochlorophyte abundant in the oceanic euphotic zone. Nature 334: 340-343.

Kana, T.M., P.M. Glibert, R. Goericke, and **N.A. Welschmeyer**. 1988. Zeaxanthin and B-carotene in Synechococcus WH7803 respond differently to irradiance. Limnology and Oceanography 33: 1623-1627.

Wright, S.W., S.W. Jeffrey, R.F.C. Mantoura, C.A. Llewellyn, **N.A. Welschmeyer**, T. Bjornland, D. Repeta. 1991. An improved HPLC method for the analysis of chlorophylls and carotenoids from marine phytoplankton. Marine Ecology Progress Series (in press).

**Welschmeyer, N.A.** and N. Hoepffner. 1990. Xanthophyll cycling I: Dynamics of rapid, light-induced pigment changes in phytoplankton. Limnology and Oceanography (in press).


### MANUSCRIPTS


DiTullio, G.R. and **N.A. Welschmeyer**. 1991. Effects of growth irradiance and nitrogen limitation on xanthophyll cycling and fluorescence quenching. Journal of Phycology (to be submitted).

Goericke, R. and **N.A. Welschmeyer**. 1991. Pigment turnover in the diatom *Thalassiosira weissflogii* I: Kinetics of chlorophyll a 14-C labeling. Plant Physiology (in revision).

Goericke, R. and **N.A. Welschmeyer**. 1991. Pigment turnover in the diatom *Thalassiosira weissflogii* II: Kinetics of 14-C labeling in carotenoids. Plant Physiology (in revision).

Goericke, R. and **N.A. Welschmeyer**. 1991. A seasonal study of the abundance and growth rates of marine Prochlorophytes in the Sargasso Sea. Nature (submitted).

Goericke, R. and **N.A. Welschmeyer**. 1991. The chlorophyll-labeling method: Measuring specific rates of chlorophyll a synthesis in cultures and in the open ocean. Limnology and Oceanography (submitted).

**Welschmeyer, N.A.** 1990. Xanthophyll cycling II: A biological tracer for upper-ocean mixing. Limnology and Oceanography (in revision).


### PH.D. DEGREE:


Goericke, R. 1990. Pigments as ecological tracers for the study of the abundance and growth of marine phytoplankton. Ph.D. Thesis, Harvard University, 418p.

# REPORT OF INVENTIONS AND SUBCONTRACTS

*(Pursuant to "Patent Rights" Contract Clause) (See Instructions on Reverse Side.)*

*Form Approved OMB No. 0704-0297 Expires Jun 30, 1992*



| 1a. NAME OF CONTRACTOR / SUBCONTRACTOR | c. CONTRACT NUMBER | 2a. NAME OF GOVERNMENT PRIME CONTRACTOR | c. CONTRACT NUMBER | 3. TYPE OF REPORT (X one) |
|---|---|---|---|---|
| SJSU University Foundation | N00014-87-K-0536 | ONR | N00014-87-K-0536 | a. INTERIM [ ] b. FINAL [X] |
| **b. ADDRESS (Include ZIP Code)** | **d. AWARD DATE (YYMMDD)** | **b. ADDRESS (Include ZIP Code)** | **d. AWARD DATE (YYMMDD)** | **4. REPORTING PERIOD (YYMMDD)** |
| P.O. Box 760<br>San Jose, CA 95106 | 870701 | 800 N. Quincy St.<br>Arlington, VA 12217-5000 | 87/07/01 | a. FROM 87/07/01<br>b. TO 90/12/31 |

## SECTION I – SUBJECT INVENTIONS

**5. "SUBJECT INVENTIONS" REQUIRED TO BE REPORTED BY CONTRACTOR / SUBCONTRACTOR (If "None," so state)**

| a. NAME(S) OF INVENTOR(S) (Last, First, MI) | b. TITLE OF INVENTION(S) | c. DISCLOSURE NO., PATENT APPLICATION SERIAL NO. OR PATENT NO. | d. ELECTION TO FILE PATENT APPLICATIONS (1) United States (a) Yes | (b) No | (2) Foreign (a) Yes | (b) No | e. CONFIRMATORY INSTRUMENT OR ASSIGNMENT FORWARDED TO CONTRACTING OFFICER (1) Yes | (2) No |
|---|---|---|---|---|---|---|---|---|
| Welschmeyer, N.A. | None to report | | | | | | | |

| f. EMPLOYER OF INVENTOR(S) NOT EMPLOYED BY CONTRACTOR / SUBCONTRACTOR | | g. ELECTED FOREIGN COUNTRIES IN WHICH A PATENT APPLICATION WILL BE FILED | |
|---|---|---|---|
| (1) (a) Name of Inventor (Last, First, MI) | (2) (a) Name of Inventor (Last, First, MI) | (1) Title of Invention | (2) Foreign Countries of Patent Application |
| (b) Name of Employer | (b) Name of Employer | | |
| (c) Address of Employer (Include ZIP Code) | (c) Address of Employer (Include ZIP Code) | | |

## SECTION II – SUBCONTRACTS (Containing a "Patent Rights" clause)

**6. SUBCONTRACTS AWARDED BY CONTRACTOR / SUBCONTRACTOR (If "None," so state)**

| a. NAME OF SUBCONTRACTOR(S) | b. ADDRESS (Include ZIP Code) | c. SUBCONTRACT NO.(S) | d. DFAR "PATENT RIGHTS" (1) Clause Number | (2) Date (YYMM) | e. DESCRIPTION OF WORK TO BE PERFORMED UNDER SUBCONTRACT(S) | f. SUBCONTRACT DATES (YYMMDD) (1) Award | (2) Estimated Completion |
|---|---|---|---|---|---|---|---|
| None | | | | | | | |

## SECTION III – CERTIFICATION

**7. CERTIFICATION OF REPORT BY CONTRACTOR / SUBCONTRACTOR** *(Not required if [ ] Small Business or [ ] Non-Profit organization.) (X appropriate box)*

| a. NAME OF AUTHORIZED CONTRACTOR / SUBCONTRACTOR OFFICIAL (Last, First, MI) | c. I certify that the reporting party has procedures for prompt identification and timely disclosure of "Subject Inventions," that such procedures have been followed and that all "Subject Inventions" have been reported. | |
|---|---|---|
| Nicholas A. Welschmeyer | | |
| **b. TITLE** | **d. SIGNATURE** | **e. DATE SIGNED** |
| Professor | Nicholas A. Welschmeyer | 9/23/91 |

DD Form 882, OCT 89 *Previous editions are obsolete.* 971284